Ultra Wideband Interference into Ka Band Satellite Systems

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Abstract- *We analyze UWB vehicular radar effects in Ka band satellite communication systems. We combine new FCC guidelines for UWB emission limits with atmospheric attenuation for intense auto traffic regions. GEO systems would be expected to suffer noticeable uplink interference at 1.2 autos per square km, and earth stations may be required to keep vehicles more than 135 meters away.*

1. Background

Ultra wideband system concepts have shown outstanding promise in the past few years. Lawrence Livermore Labs experimented with carrierless nanosecond pulses and showed that mine detectors could clearly discriminate between anti personnel and antitank mines. Time Domain Inc. showed the value of similar pulse design for several kinds of communication. Daimler-Chrysler recognized the value of short pulse widths and precision ranging for vehicular use. They chose center frequencies much higher than the Lawrence Livermore examples, and required carriers near 24 GHz. Bandwidths would be on the order of one GHz and ranging accuracy on the order of 30 cm. One of the Daimler Chrysler concepts used antennas with 30 dB gain, with four per auto.

The Federal Communications Commission (FCC) also recognized the value of vehicular radar. They ruled in favor of a large class of ultra wideband devices (1) in February of this year. *Unfortunately,* they allowed a band much larger than the original Daimler-Chrysler concept (D thin spectrum of Fig. 1-1).

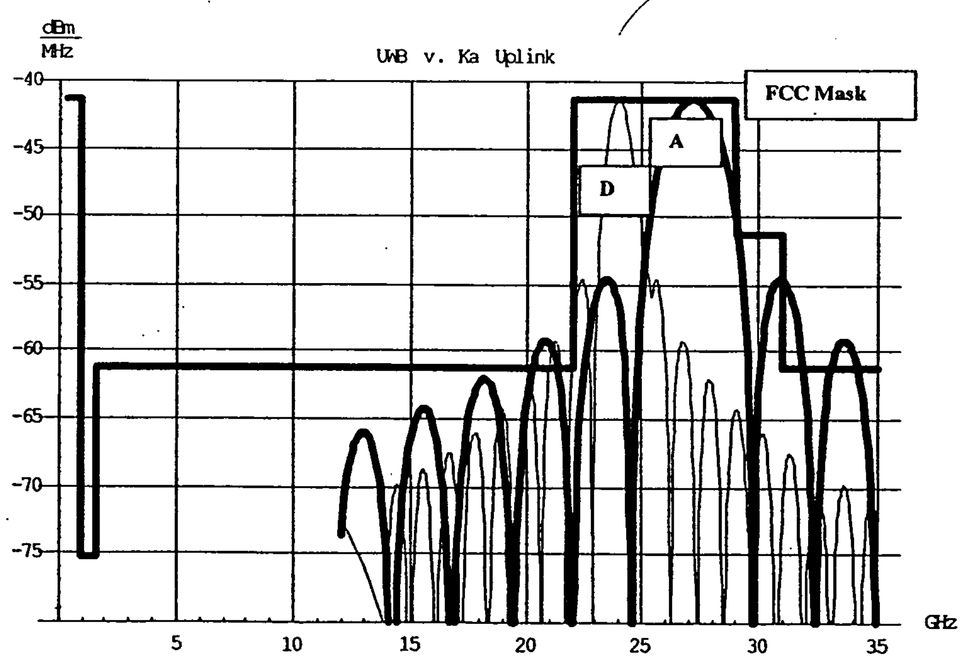

Fig. 1-1 Allowable Vehicular UWB Emissions Spectra under FCC Mask (2/02)

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Fig. 1-1 shows the permissible FCC emissions as much wider than the Daimler-Chrysler concept, and a special concern to Ka uplinks is shown as the thick spectrum centered at 27.2 GHz (A). This paper will address the concerns that the FCC ruling implies for Ka band satellite systems. First, we discuss the interference that 27-29 GHz vehicular radars would introduce on the uplink. Then, we recognize that UWB signals would be permitted to fill the entire 22-29 GHz band and we address the implications for the downlink.

2. UWB Uplink Interference

The satellite antenna may see large areas of the earth on the uplink. Fig. 2-1 shows the view from a GEO at 0E. New York and the northeastern U.S. are visible on the limb. A single spot beam from the satellite could cover the entire northeastern U.S.

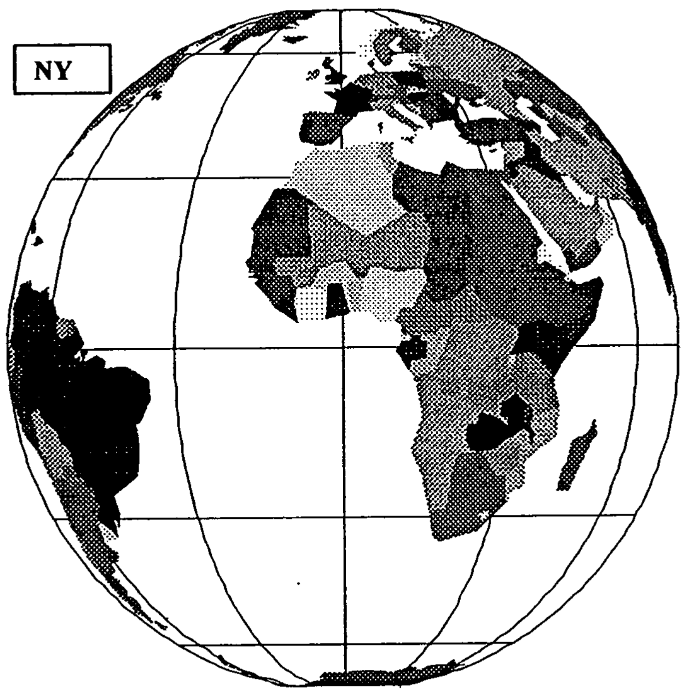

Fig. 2-1 View from a GEO at 0E. Note New York at Upper Left

The basic equation for received on the uplink power may be shown as:

$$Pr = \frac{Gr\ Gt\ Pt\ \lambda^2}{16\,\pi^2\, r^2} \qquad \text{2-1a}$$

and an extra factor for atmospheric attenuation as:

$$\text{Atmospheric Attenuation} = 10^{-A} \qquad \text{2-1b}$$

where Pt is UWB transmitter power= $10^{-(71.3/10)}$ Watts/MHz (-41.3 dBm/MHz)

λ = wavelength, m; as 0.01m at Ka band.

gt= UWB power gain

gr= satellite dish gain (1 m dish for examples), as (Pi/0.01 $)^2$

r= distance to interference source, m; as 40,000,000 m for examples below.

A=atmospheric attenuation (dB)

Eq. (2-1a) is multiplied by (2-1b) to get received power as a function of frequency for this discussion.

UWB Antenna Gain

Unlike other UWB devices that are largely nondirectional, the vehicular UWB is intended to be directional. Daimler-Chrysler mentioned a main beam gain as 30 dB during early descriptions of their devices. This would imply an antenna aperture diameter as 11.8 cm for center frequencies near 25.5 GHz. The antenna gain might be represented as the polar plot of Fig. 2-2.

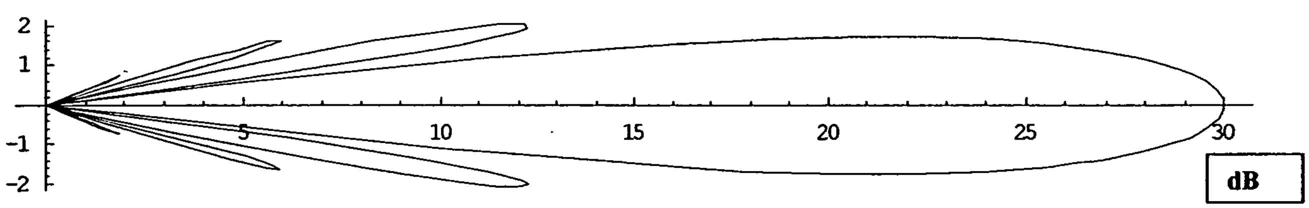

Fig. 2-2 Polar Plot of Vehicular UWB Gain; Note Beamwidth as 5.7°

The average gain for the antenna rotated in azimuth must include the main beam gain of 1000, but it also includes a large array of infinitesimal gains. The average gain for the azimuth scan may be found to approach 17.

(As an aside, we note that the complete average for gain over a hemisphere is unity, as it must be for a passive device. The average for an azimuth scan is higher because the main beam hits the observer on every scan.)

Atmospheric Attenuation

Barbaliscia, Boumis, and Martellucci (2) developed comprehensive worldwide attenuation maps which included the critical 49.5 and 22.2 GHz cases. These could be solved for estimates of water vapor and cloud attenuation to yield a general attenuation function (3) in the 10-100 GHz range. Fig 2-3 shows the derived attenuation map for 30 GHz. We also saw that attenuation could be traded against the higher gain at higher frequencies, and optimum frequencies (in the sense of maximum signal at constant aperture) much higher than 30 GHz could be found (4).

Fig. 2-3 is modified for GEO attenuation in Fig. 2-4. GEOs are closely related to the benefits of Ka band communication even more than some other orbits (Appendix).

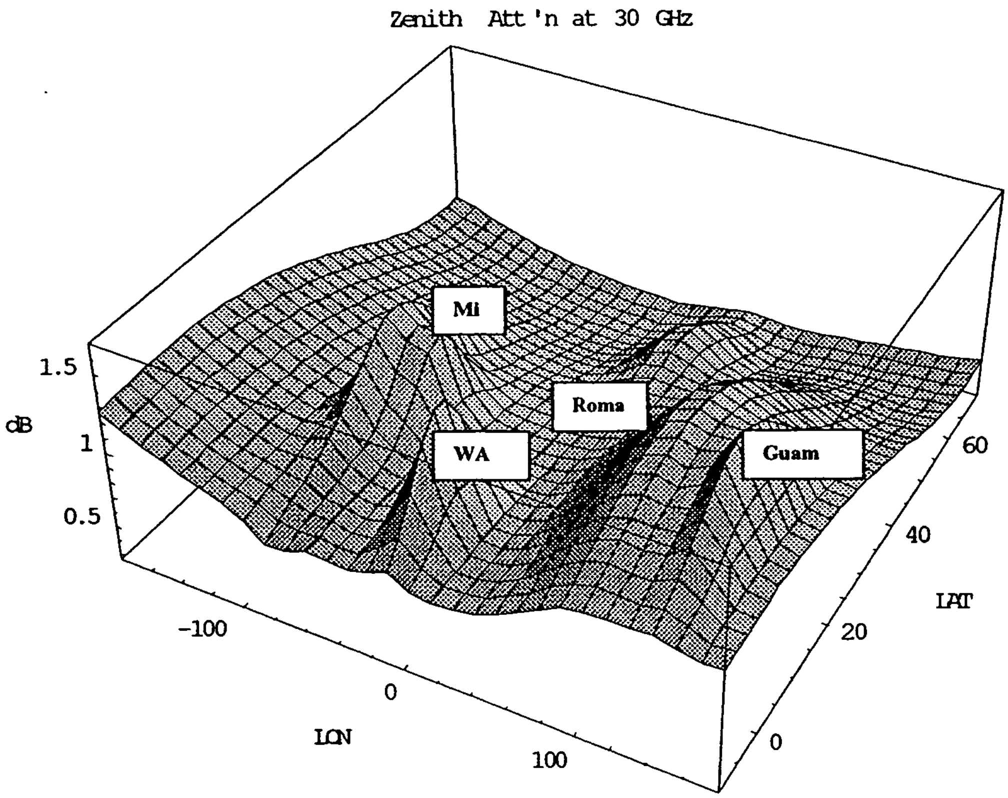

Fig. 2-3 30 GHz Zenith Attenuation, as Derived from Barbaliscia's Attenuation Maps; Note Miami (Mi), West Africa (WA), Guam

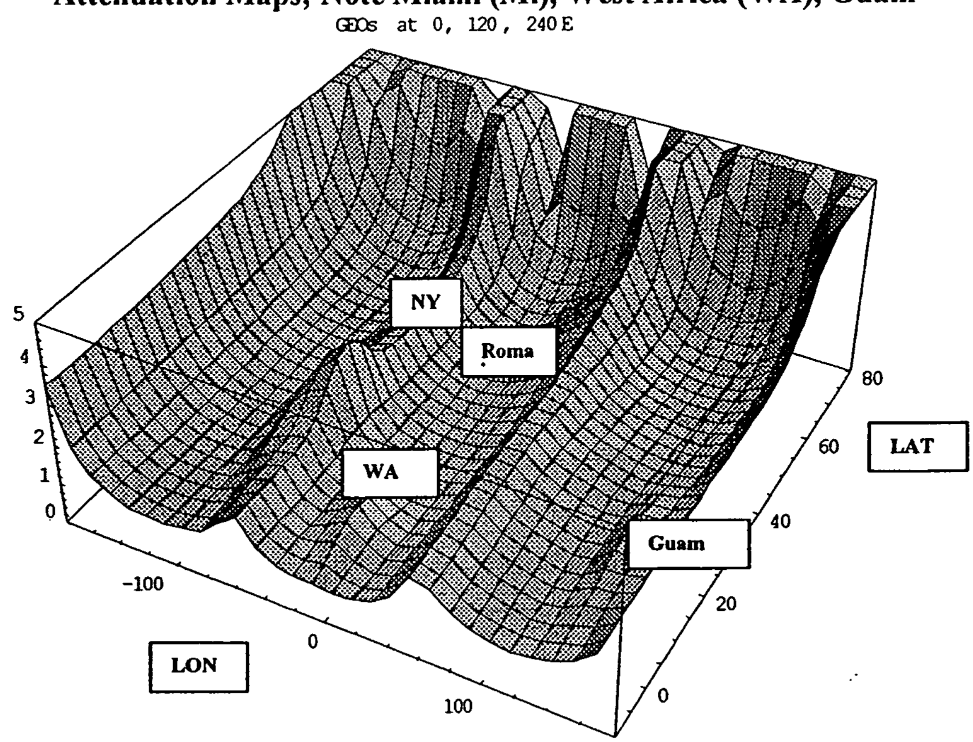

Fig. 2-4 GEO Attenuation for 0°, +120°, -120° E Locations; Note New York

The derived attenuation model gives attenuation for arbitrary locations (e.g., New York, Iceland) for a range of frequencies up to 100 GHz as shown in Fig. 2-5.

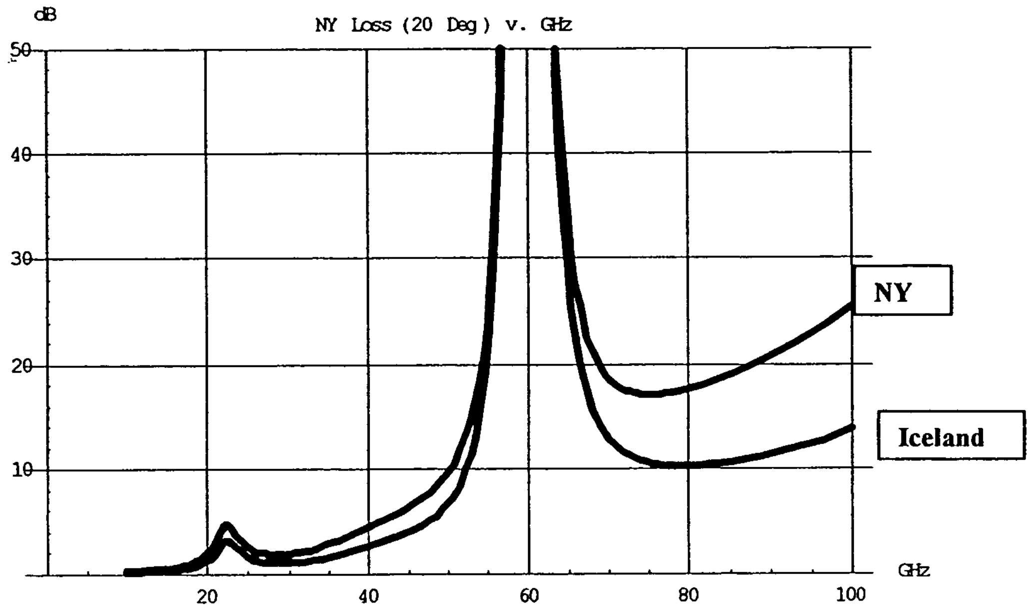

Fig. 2-5 Attenuation (dB) at 20 Degrees Elevation v. Frequency

The UWB interference may also be expressed as a loss, in this case an excess noise loss. Fig. 2-6 uses a million UWB vehicular radars, centered at 27.2 GHz, to generate uplink interference into a 200K satellite receiver. The excess noise, due to the interference, is added to the NY atmospheric loss. A UWB penalty is visible at 27-29 GHz.

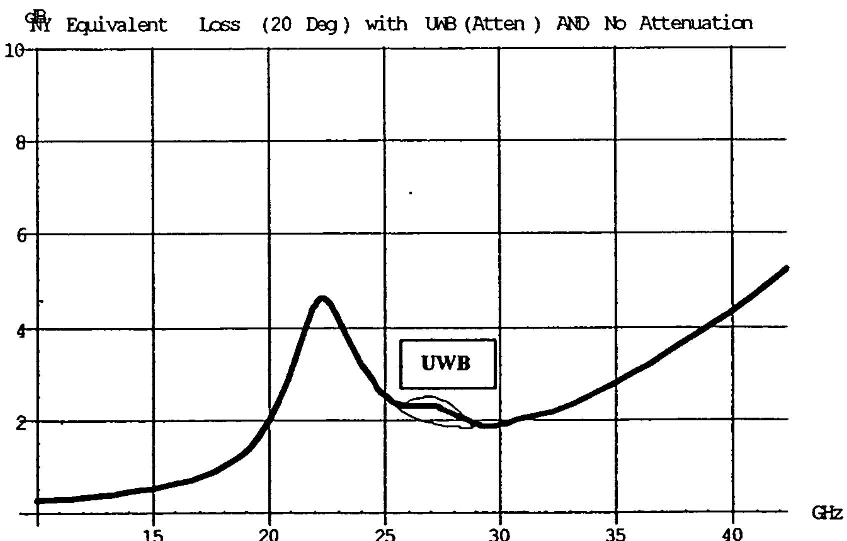

Fig. 2-6 New York Loss Plus UWB Uplink Interference (10^6 autos;1.2/km^2)

Fig. 2-6 assumes that one million vehicles may be in the satellite spot beam. With a population approaching 50 million in the northeastern U.S., this may be a reasonable assumption. Other regions, such as Tokyo, would have a much higher density population in the same 0.5 degree spot beam. The entire population of Japan might be in the spot beam if the GEO were stationed at the Indian Ocean. What might we expect for performance degradation if ten million vehicles, equipped with UWB, were in the spot beam? Fig. 2-7 suggests very sharp degradation in the Ka uplink performance.

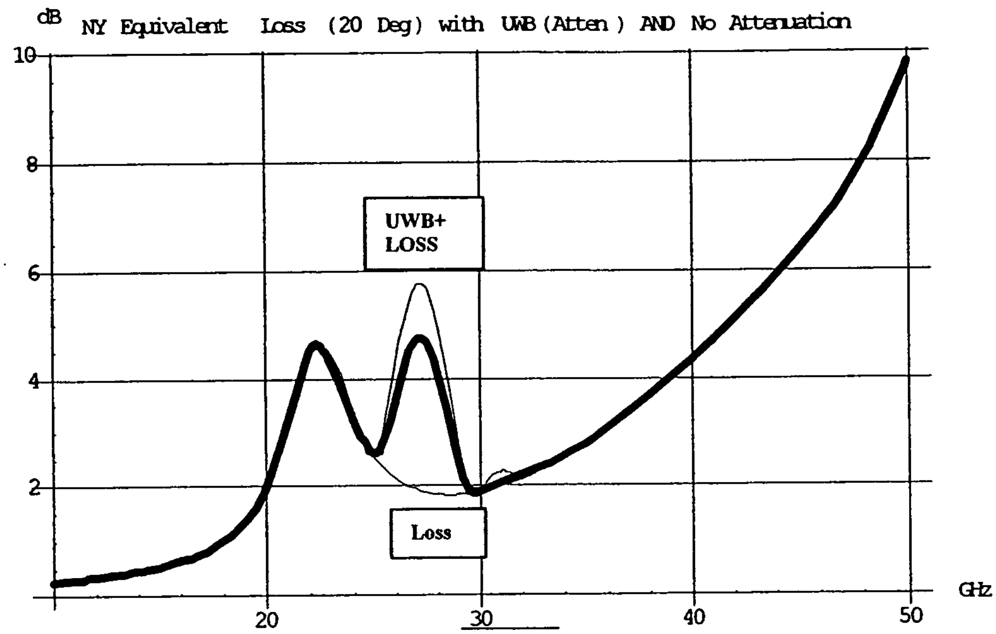

Fig. 2-7 New York Loss Plus UWB Uplink Interference (10^7 autos; 12/km^2)

Fig. 2-7 represents a (nearly) worst case, with 10 million vehicles operating at once in the spot beam. It would offer such strong interference that even the UWB sidelobes (see the thick spectrum A of Fig. 1-1) would be visible.

3. UWB Downlink Interference

The FCC emissions mask allows a much broader spectrum than the Daimler-Chrysler spectrum, as Fig. 3-1. The allowable vehicular spectrum as shown by Fig. 3-1 implies a high first sidelobe in the 19-20 GHz region. This may be a concern for Ka band downlinks. The FCC could alleviate this concern if they do emissions tests for the whole mask, rather than restricting the emissions tests to the obvious band between 22-29 GHz. The –55 dBm/MHz level will relate to the interference distance discussion below.

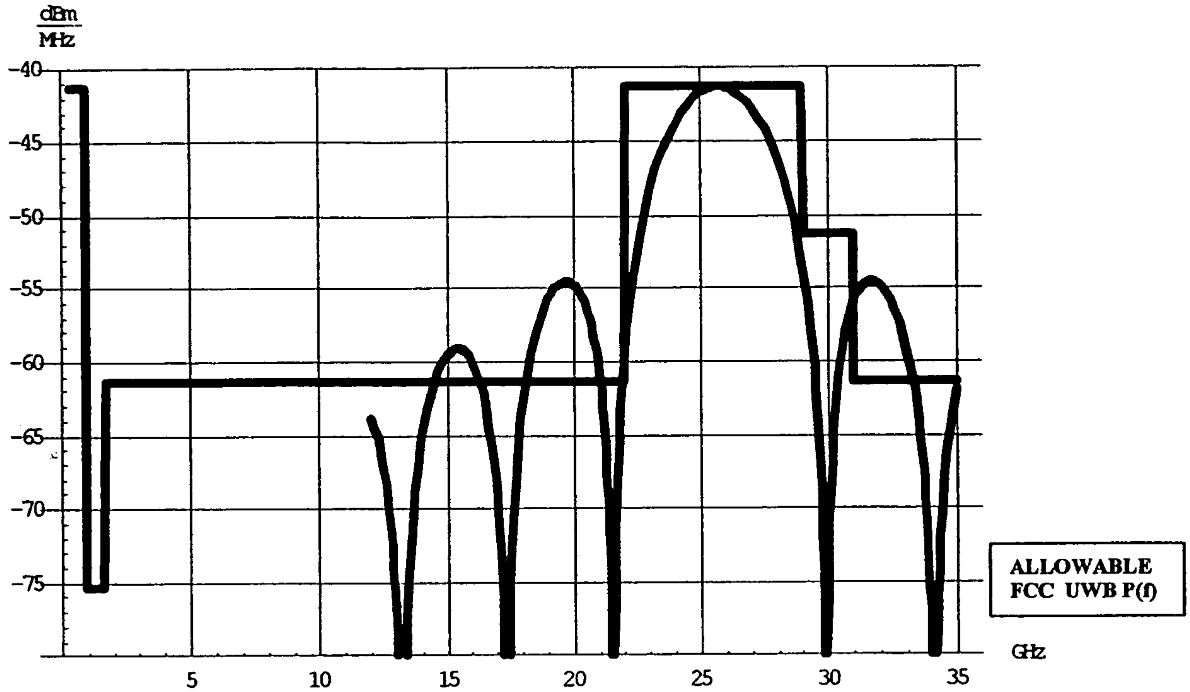

Fig. 3-1 Broad Vehicular Radar Spectrum Allowed by the FCC Rules

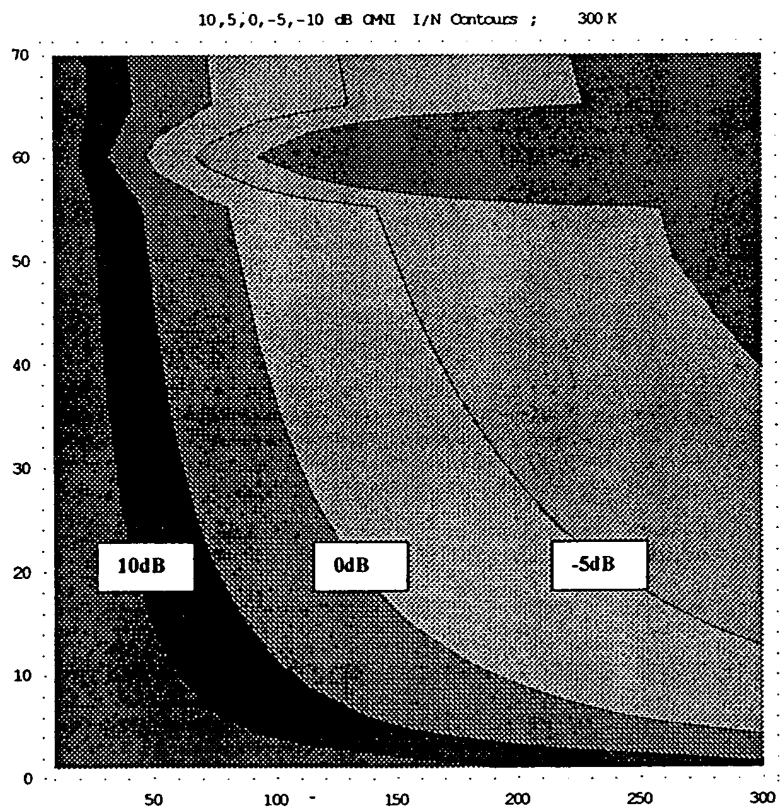

Fig. 3-2 Interference (INR) Contours for Frequency v. Distance (m)

The interference distances are actually functions of the statistical gain patterns. The 135 meters suggested by Fig. 3-2 for interference distance would be representative only for UWB power gain as 17 and the Ka earth station antenna gain as unity. We note also that the –5 dB INR level corresponds to a distance of almost 250 meters. Operators of Ka 30/20 GHz ground terminals might consider keeping such devices almost 250 meters away from the terminal.

Conclusions

We used Barbaliscia's invaluable attenuation maps and an FCC UWB emissions mask to show that UWB vehicular density greater than 1.2/ km^2 may be a concern for Ka band uplinks. In addition, vehicles equipped with UWB radar may need to provide 135- 250 meters protection distance to Ka band downlinks.

Acknowledgements

Kurt Nahser and Richard Bertram of Odyssey provided valuable UWB discussions.

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S. Wolfram, **Mathematica A System for Doing Mathematics by Computer,** 3rd Edition, Wolfram Research, 1997.

S. Wolfram, **A New Kind of Science**, Wolfram Media Inc., 2002.

Mathematica programs for worldwide attenuation for 10-100 GHz and optimum frequency selection are available at pfchristop@aol.com

Appendix Optimum Frequencies for a GEO Satellite

GEO satellites have a special need for viable Ka band operations because they have a limited choice of higher frequencies. Atmospheric attenuation may be combined with the frequency dependent gain advantages (3,4,5) of constant aperture antennas to find 'optimum' frequencies. A thorough search of net loss in the 20-40 GHz region shows optimum frequencies grouping closely around 28-34 GHz for a satellite in mid- Atlantic. Fig. A-1 shows these attractive frequencies for a GEO at 345E. The massive pit in the foreground of the figure is due to the severe attenuation off West Africa.

In contrast, highly elliptical satellites (3,4,7) may have much less attenuation in the Temperate regions. Fig. A-2 indicates optimum frequencies jumping abruptly to over 80 GHz at 45 North. The frequency at Rome rises sharply to the 44 GHz region.

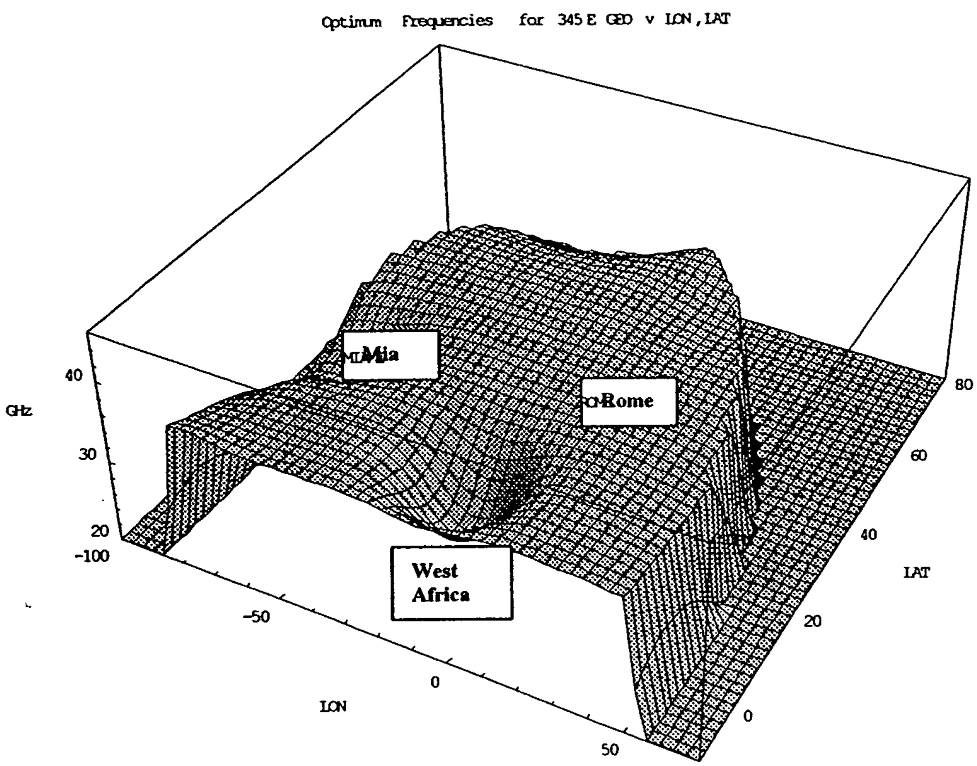

Fig. A-1 Optimum Frequencies for a GEO at 345E; Rome at 32-34 GHz

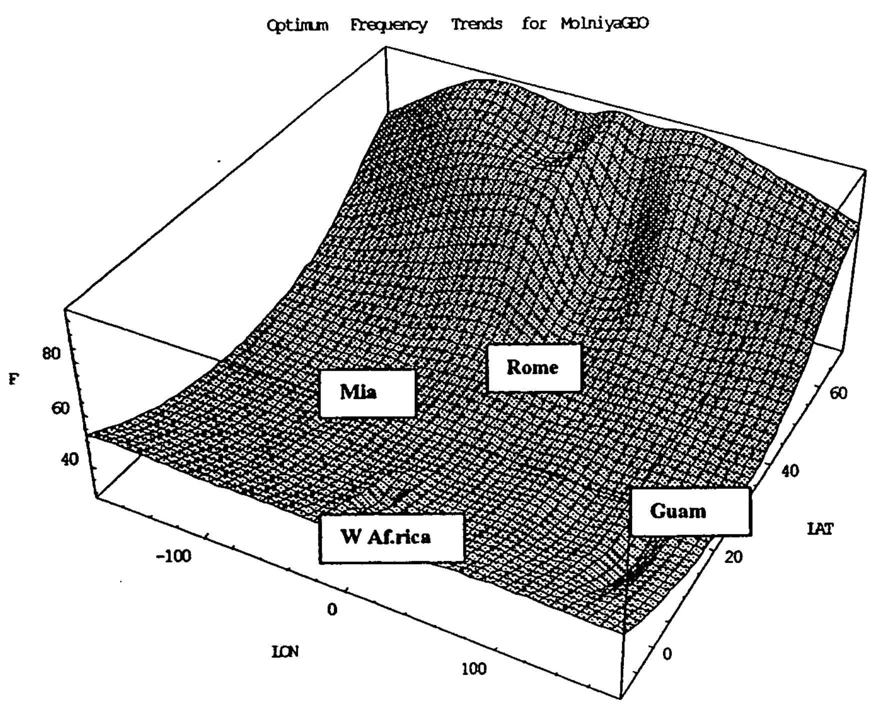

Fig. A-2 Optimum Frequencies for HEO-GEO Combination; Rome 44 GHz